

## **Bathymetric 3D Synthetic Aperture Sonar**

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### **LONG-TERM GOALS**

To produce “optical quality” 3-D images of the seafloor using a wide bandwidth, side-looking, synthetic aperture sonar capable of operating in shallow-water with possible applications in mine counter measures.

### **OBJECTIVES**

- (1) To become involved in the hardware /software design and operation of the new “Slow speed SAS” currently being built by Northrop Grumman.
- (2) To show the value of extending a standard SAS to having true 3-D or bathymetric capability.
- (3) To contribute to the mine burial experiment in Tampa Bay, FL, in the winter of 2003. To that end we would like to get our new 3-D bathymetric SAS as well as the Northrop Grumman Slow speed SAS on site to image the same target field.

### **APPROACH**

Because of the vast geographical distance and the fact that the Acoustics Research Group is university based, our whole approach to the problem of seafloor imaging is somewhat independent of the government or commercial thrust of our northern hemisphere SAS colleagues. For example, we design and build our own transducers, towfish, amplifiers, computer systems, write all our own software and even run our own ship on experimental sea trials.

This independence has advantages and disadvantages. Advantages include not being dependent on fluctuating funding. Since our academic salaries are by and large covered by our teaching commitments, the only cost we must cover are for operational costs and the consumption of raw materials. (However increasing competition for graduate students means that attractive student stipends are now becoming a necessity.) Other advantages include a rapid planning and execution of real experiments. About 48 hours is all it takes to go between planning an experiment to being at sea doing the experiment. Contrast this with the years it might take for a single experiment to be proposed, funded, planned and executed at CSS or Raytheon.

The disadvantages include being isolated from rapid advances in the underlying technologies taken for granted by our northern hemisphere colleagues. Also the scale of our experiments are very restricted. Since we deploy our target fields in a commercial waterway, we have to remain on station while the targets are down. This precludes monitoring the seafloor burial and scouring processes of target we deploy. The discontinuous nature of our experiments leads to a significant problem for us. Since we are the only people involved in the experiments, there is a problem with credibility. We have had little independent corroboration of our capabilities and results. The exception being the experiment done for the Defence Science & Technology Organisation of the Australian Navy in Sydney Harbour. To rectify this credibility problem, we must get involved in cooperative work with the major government and commercial groups in the northern hemisphere such as ONR, CSS, Raytheon and Northrop Grumman..

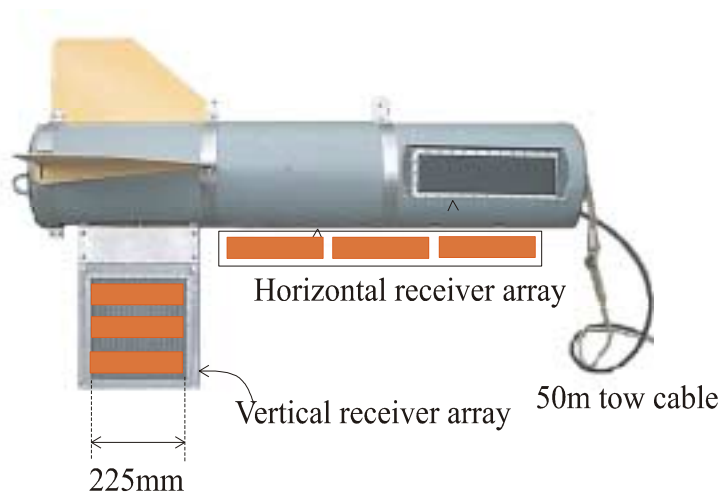
The two key academics in the ARG are Dr Michael Hayes and myself. Both of us have been in the SAS field for a very long time now and have complementary skills. Dr Hayes is a specialist in electronic hardware, embedded software and software engineering. He plans and supervises all the work involving real-time data analysis and computer systems. My areas of expertise are in the mechanical design of the underwater towed bodies and housings as well as algorithm development for efficient image reconstruction.

We currently have a group of talented graduate students all with specific areas of responsibility. The first two are involved in attempting to counteract the errors in the path trajectory. Since the SAS procedure assumes a perfectly straight flight-path, any departures from this assumption due to sway result in imaging errors. Haden Callow continues to develop autofocussing algorithms to calculate these sway errors based largely on the PGA approach of the spotlight SAR community. Steven Fortune also works on autofocussing approaching it as an optimising problem. Given our measured data, what is the most likely image and the most likely path trajectory? Both are right now presenting their work at the IGARS Symposium 2001 in Sydney and at the IEEE Oceans 2001 in Hawaii (Callow et al, 2001; Fortune et al, 2001).

The next two students work on the problem of navigation of the towfish. Edward Pilbrow designs and programmes our electronic navigation package inside the towfish while Alan Hunter attempts to use the statistics of the seafloor to get a gross measure of the towfish path (although his prime responsibility is to model the effect of the moving sea surface on multipath impairments to the imaging process). On board the fish we have a two-axis interclinometer to measure the pitch and roll to about one degree of absolute accuracy. Since this instrument is gravity referenced, we regard this as our most accurate on-board instrument which we can use to calibrate our other instrument package made by 3DM. This package includes a three-axis magnetometer which measures the earth's magnetic field and, with suitable calculations, computes the pitch, roll and yaw of the towfish. We compare the pitch and roll of the 3DM magnetometer with those measured with the interclinometer and determine absolute yaw to a few degrees. Since a SAS is only concerned with relative yaw during the time duration of the

data collection process (a few 10s of seconds), the absolute error is not as much a concern as the differential error which appears to be as small as a fraction of a degree. Finally the 3DM instrument package also contains a 3 axis accelerometer for estimating sway, heave and surge. We have yet to calibrate these sensors.

The bathymetric SAS is the prime responsibility of Philip Barclay. This will be the major area of our work for the next few years so we will be augmenting his particular contribution with more graduate students next year. This aspect of our work here is unique as we believe we have the first sea-going free-towed bathymetric SAS in existence. Once again this is a development first shown feasible by our SAR colleagues but they of course have it easier thus us with the better instrumented path trajectory and the greater stability of their medium. Our approach is to increase the number of images recorded. We intend to form six images of every scene. Firstly we have a high and low frequency band: one covering 20-40kHz and one 95-115kHz . Secondly, we have three rows of hydrophones each forming an image from a different height off the seafloor see Figure 1. The difference between any two images at the same frequency is enough to show a phase structure that overlays the image. By phase unwrapping (the same process as in SAR interferometry), we can get an estimate of the 3-D structure of targets in the field of view. The ambiguity problems normally associated with phase unwrapping can be solved by the multiple frequency-band, multiple view images produced by our SAS (Lanari et al, 1996). We would anticipate this being a long-term goal that may take several years to perfect. Currently we deploy only the vertical receiver array. The horizontal receiver array shown in Figure 1 has yet to be fitted.



*Figure 1 The Bathymetric 3-D multi-hydrophone SAS*

**TRAVEL COMPLETED**

**Table 1. Summary of visits conducted under this VSP.**

Person Visited	Position	Institution / Conference	Location	Scientific / Technical Purpose	Dates (mm/dd/yy format)
Dr Roy Wilkens	Program Officer	ONR	ONR HQ Fairfax, VA	NICOP sponsorship	06/27/01
Mike	SAS Project	Northrop	Annapolis	SAS	06/28/01

Wazenski	manager	Grumman		Workshop	06/30/01
Dr Jim Christoff	SAS Program leader	CSS	NSWC, Panama City, FL	SAS progress report	07/02/01
Dr Ed Linsenmeyer	NICOP contact	CSS	NSWC, Panama City, FL	NICOP support	07/03/01

## RESULTS

**Visit to ONR HQ** The discussion with Dr Roy Wilkins was very useful in understanding how ONR supported external projects. Unfortunately being 4<sup>th</sup> July week, neither Doug Todrooff nor Bruce Johnson were available and clearly our work here at Canterbury is more aligned to Mine Counter Measures than Marine Geosciences. However, Wilkins did advise me that Bruce Johnson would be the correct person to submit any NICOP request through, especially if we wished to be part of the Tampa Bay, Mine Burial Experiment.

Note: The original travel plan had me to visit Dr Ed Franchi at NRL but unfortunately he was not available at all during that week.

**Visit to Northrop Grumman:** The most meaningful outcome of the visit was to persuade Northrop Grumman that modern SAR-based image reconstruction techniques will be needed to handle the data rate expected from their new multi-hydrophone array SAS currently under design and construction. To this end, Northrop Grumman's Systems Engineering Manager (Oceanic and Naval Systems), John Aberg, has agreed (verbally) to provide seed money for a future NICOP proposal although this would be specifically to look at how an extension to show how a 3-D Bathymetric SAS may improve the imaging ability of any SAS system.

The most meaningful technical result was for me to understand how an efficient beam-forming algorithm could be written for a modest proportional bandwidth SAS such as the new Northrop Grumman slow speed SAS. The brutal straightforward beam-forming technique is to up-sample to incoming base-band data by 10 to 16 times so as to achieve sub-sample delay times in the "delay and sum" algorithm. For modest bandwidth SAS sub-sample delays can be approximated by full sample delays and subsequent phase adjustment. This can be computed very efficiently. The slow speed SAS under design has a 30% center frequency to bandwidth ratio and is a candidate for this algorithm. So a possible outcome would be for a combined image reconstruction process where a SAR-based algorithm is used for real time operation and reconnaissance imaging followed by a non-real time beam-forming based algorithm to touch up the areas of the image deemed important.

**Visit to CSS:** The most meaningful result of my visit to CSS was to show them how we deal with yaw errors in a multiple hydrophone array SAS. Up until quite recently all of us (that is, SAS researchers in CSS, Raytheon, Northrop Grumman and the ARG) had the impression that unknown yaw errors would be the largest single problem limiting high-quality SAS imagery. As a result of some work we have just completed for Raytheon, it appears that yaw errors can be measured from the data to a high degree of accuracy. No doubt CSS and Northrop Grumman will run some simulations and tests on their data to see if our contention is correct.

Finally, a meeting with Ed Linsenmeyer clarified some of the procedures needed for a future NICOP request.

## **IMPACT/APPLICATIONS**

There are clear prospects of important collaborative links between several players in the SAS field. In the past the Acoustics Research Group (ARG) at the University of Canterbury has done collaborative research with Hughes Maritime (now Raytheon Electronic Systems) and the Coastal Systems Station, NSW. This visit, supported by ONRIFO, is the first formal contact we have had with Northrop Grumman. I believe they can see an obvious benefit in having us involved in the signal processing aspects of their slow speed SAS project. Since CSS is also involved, there appears to be a CSS/Northrop/ARG cooperative thrust to ensure that this new SAS will deliver all that it promises. There is little doubt that the specifications of the slow speed SAS are bold and it will take a concerted effort for all contributing parties to get the best from this system.

## **TRANSITIONS**

One of the major contributions the ARG can make to the slow speed SAS project is to provide independent simulations of both the data collection process and the image reconstruction process. So far the ARG has (as part of the workshop last week) provided Northrop with SAR-based image reconstruction software as well as software to mimic the data collection process. Since these are written completely independently of their own software teams, they function as a perfect “sanity check”. If their image reconstruction software works perfectly on our simulated data and our image reconstruction software works perfectly on their simulated data, then we all have a great deal of confidence that both sets of software are doing what they are designed to do.

In the ARG we have always made our non-specific software available to anyone who requests it at no charge in a similar way to the GNU Public Licence or Berkeley Software Distribution protocols. We would continue to use this method of disseminating useful software to the SAS community at large.

## **RELATED PROJECTS**

There are several related SAS projects currently under way in the ARG.

We have a one-man project (Loic Sibeaud) looking at effective ways to multiplex the data up the cable. We currently have a four twisted-pair wire system, which we can use in a straightforward manner with four hydrophones. When we go to a 3-D bathymetric SAS with an along fish hydrophone array (see Figure 1) we will need to either change our cable to many more pairs of wire or use some form of (probably digital) multiplexed system.

My colleague Dr Michael Hayes has a project planned to investigate ways of using our Beowulf cluster of LINUX boxes running a MOSIX modified kernel to increase our real time computing ability. Our cluster currently comprises 22 Dual Pentium III computers and MOSIX would designate a “head node” to do all the housekeeping and parcel out the calculations to the other processors. We anticipate one or two processors doing nothing but estimating the yaw and sway corrections needed while the bulk of the processors work on the data from each individual hydrophone and a few processors doing nothing more than a final imaging mosaic and display. At this stage we have no idea if the fast 100Mb/s Ethernet link between processors will have enough bandwidth to handle the data flows without constipation.

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